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Remote Monitoring of Coal Strip Mine Rehabilitation

Lockheed Electronics Co, Inc, Las Vegas, NV Remote Sensing Lab

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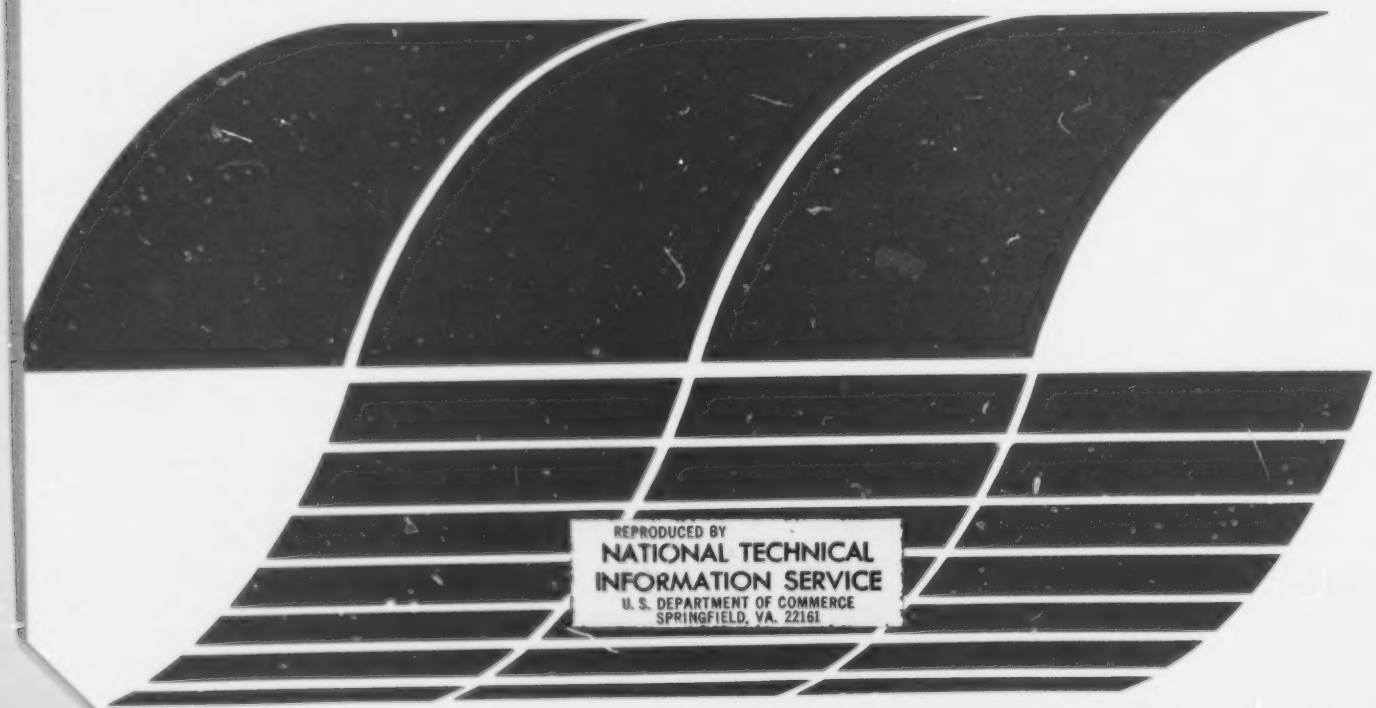
Remote Monitoring of Coal Strip Mine Rehabilitation

Interagency Energy-Environment Research and Development Program Report



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This report discusses the accomplishments of the Phase I Operations of the EPA/NASA joint project and also compares the results of manual photo-interpretation and automated data analysis conducted during this phase. Also included in this report are the results of a feasibility study to utilize Landsat data for performing a regional land-cover classification of a portion of the Powder River Basin area in northeastern Wyoming, where there are numerous coal strip mines.

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REMOTE MONITORING OF COAL STRIP MINE REHABILITATION

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report discusses and evaluates the utility of aircraft multispectral scanner data as a tool for monitoring surface strip mining operations in the northern Great Plains and the western portion of the United States. It also demonstrates the feasibility of using Landsat data as a regional planning tool for pre-mining environmental impact evaluation. Procedures and techniques used in processing digital data and interpreting aerial photographs of selected strip mines are also demonstrated. This report should be of interest to those State and Federal agencies who have the responsibility of enforcing the recently passed Surface Mining and Reclamation Act of 1977.

George B. Morgan

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Director
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ABSTRACT

The U.S. Environmental Protection Agency (EPA) and the National Aeronautics and Space Administration (NASA) entered into a five-year, EPA-funded project to transfer hardware and software technology for processing remotely sensed digital data obtained from aircraft or satellite platforms.

This project was divided into three phases. Phase I was an 18-month task. During this time, state-of-the-art technology for processing aircraft-acquired multispectral scanner (MSS) data was transferred to the Environmental Monitoring and Support Laboratory in Las Vegas, Nevada (EMSL-LV). Also, Landsat and aircraft multispectral scanner data and photographic data over coal strip mines in the Western United States were analyzed using basic pattern recognition techniques refined and/or developed at the NASA/Earth Resources Laboratory (ERL) in Slidell, Louisiana.

This report discusses the accomplishments of the Phase I operations and also compares the results of manual photo-interpretation and automated data analysis conducted during this phase. Also included in this report are the results of a feasibility study to utilize Landsat data for performing a regional land-cover classification of a portion of the Powder River Basin area in northeastern Wyoming where there are numerous active coal strip mines.

Phase II of the joint project will be of 18 months duration. EMSL-LV will use the system for monitoring selected coal strip mines in the west, and ERL will pursue research tasks identified during Phase I.

Phase III will be 2 years in duration during which EMSL-LV will test the system in an operational mode with continued software development and assistance from NASA/ERL.

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ENGLISH-to-METRIC CONVERSION TABLE

English Unit	Metric
1 Foot	0.3048 Meters
1 Inch	2.54 Centimeters
1 Inch	25.40 Millimeters
1 Mile	1.609 Kilometers
1 Square Foot	929.03 Square Centimeters
1 Square Foot	0.0929 Square Meters
1 Acre	0.404 Hectare

SECTION 1

INTRODUCTION

The U. S. Environmental Protection Agency (EPA) and the National Aeronautics and Space Administration (NASA) entered into a five-year, EPA-funded project in the summer of 1975. The purpose of this interagency project was to transfer hardware and software techniques for processing remotely sensed digital data from NASA to EPA in order that EPA could develop the capability of establishing and maintaining a fully operational remote sensing monitoring system. This system would not only incorporate maximum utilization of EPA's present aircraft capabilities, but would allow for the integration of currently available and proposed Landsat multispectral scanner (MSS) data.

Both agencies have designated laboratories through which the five-year plan is being implemented. The NASA/Earth Resources Laboratory (ERL) located in Slidell, Louisiana, and the EPA/Environmental Monitoring and Support laboratory in Las Vegas, Nevada (EMSL-LV), are the two agency laboratories involved. Unless otherwise indicated, "ERL" and "EMSL-LV" are used to refer to these two laboratories respectively.

The overall objective of this five-year project is to define, develop, and demonstrate operational remote sensing techniques to rapidly monitor, in a cost-effective manner, the success with which an energy-related extration site has been, or is being rehabilitated to a state suitable for its intended or previous land usage. The specific objectives are to:

- Transfer the data analysis system and its associated software technology and maintenance requirements to EMSL-LV
- Perform automated analysis of aircraft MSS data and manual classification of photographic data over selected coal strip mine sites
- Determine the utility of Landsat MSS data for performing a regional land-cover classification of a portion of the Powder River Basin
- Compare the results obtained from the aircraft MSS classification with the photo-interpretation results

The two agencies agreed to divide the five-year project into three distinct phases based on operational requirements. Phase I, which began in July of 1975, encompased an 18-month period during which the following activities were conducted:

(1) A Data Analysis System (DAS) was defined and assembled at ERL, checked out, and in January 1977, was transferred to EMSL-LV.

(2) EMSL-LV personnel received training at ERL in the use of the DAS for processing aircraft and Landsat acquired multispectral scanner (MSS) digital data.

(3) ERL defined an airborne multispectral scanner Data Collection System for installation into an EMSL-LV aircraft.

(4) A NASA aircraft equipped with a multispectral scanner and camera was used to acquire scanner data and aerial photography over selected coal strip mines in western United States.

(5) Vegetation/land-cover classification of the selected mine sites was produced at ERL using the scanner data and computer-implemented pattern recognition techniques, and at EMSL-LV through use of the aerial photography and manual photo-interpretation techniques.

(6) One set of Landsat acquired MSS digital data was processed at ERL to gain insight into approaches and techniques for producing land-cover classifications for regional monitoring.

This report focuses on the results of activities (5) and (6). However, technical details of the data acquisition, data processing, and analytical procedures are addressed in the text and in the appendices. The particular objective was to develop and demonstrate the techniques and procedures for deriving vegetation/land-cover classifications of coal strip mine sites and their near environs for the purpose of subsequent monitoring of the rehabilitation of mined areas. The results are analyzed with respect to the vegetation/land-cover classes that were spectrally separable and the areal extent of each class. In addition, a comparison of results from multispectral scanner data and aerial photography is made.

Phase II of the project was begun in January of 1977, and will last for 18 months. During this phase, EMSL-LV will use the system on a shakedown basis for monitoring purposes. Also during this time, ERL (utilizing a similar system) will investigate those problems specifically defined by EMSL-LV which require additional research. New techniques developed to solve these problems will be transferred to EMSL-LV at the end of this phase.

During Phase III, EMSL-LV will test the system in an operational mode for 2 years. ERL will provide continued assistance in the use of the system and supply additional software programs as they are developed during Phases II and III.

SECTION 2

CONCLUSIONS

The results of Phase I analyses indicate the feasibility of using aircraft-acquired multispectral scanner data for monitoring and evaluating coal strip mine rehabilitation activities. These results support the following specific conclusions:

- Multispectral scanner data acquired by an aircraft at an altitude of approximately 12,000 feet (3,660 meters) appears to possess sufficient spatial resolution (element size) and spectral resolution (band location and width) for vegetation/land-cover classifications of western coal strip mine sites and their near environs.

- A chi-square analysis showed no significant differences in the results of the land-cover mapping achieved through computer-implemented techniques and the land-cover mapping resulting from conventional photo-interpretation methods for the land cover classes included in the analysis.

- Adequate details of land-cover features can be obtained at 12,000 feet (3,660 meters). It is further concluded that the additional details gained from low-altitude coverage would not compensate for the necessary increase in data processing.

- Results of the preliminary land-cover classifications of a large area using Landsat data were sufficiently encouraging to proceed with a more detailed study of the use of Landsat MSS data for regional analysis.

SECTION 3

RECOMMENDATIONS

Based on the results and conclusions from Phase I Operations, the following recommendations are proposed for consideration in Phase II of the project:

- Define and conduct a task for use of Landsat data for regional analysis in Phase II of project
- Investigate the geometric correction of aircraft-acquired MSS data, in order that the land-cover/vegetation maps derived from this data can be fit to topographic maps of specific scales
- Develop techniques for reducing ground truth efforts required for monitoring after a baseline land-cover/vegetation classification has been produced
- Continue acquiring and processing aircraft-acquired MSS data for the purpose of establishing operational procedures

SECTION 4

DATA ACQUISITION

AIRCRAFT DATA

Data acquisition was scheduled to occur during the months when the chlorphyll content of vegetation was at its maximum at the selected coal strip mine sites (Figure 1). This "peak-green window" was determined by making inquiries of the reclamation specialist on each of the mines being studied. From these contacts, it was ascertained that Montana, Wyoming and Colorado have peak-green conditions that can occur from the last week of June through the first two weeks of July. Arizona and New Mexico peak-green conditions occur in late September.

The following aircraft data collection sensors and parameters were required for each flight line flown:

(1) Multispectral scanner data collection at altitudes of 3,000, 6,000, and 12,000 feet (914, 1,828, and 3,657 meters) above mean terrain elevation

(2) Photographic coverage at altitudes of 1,000, 3,000, 6,000, and 12,000 feet above mean terrain elevation (305, 914, 1,828, and 3,657 meters), using both color and color-infrared films with 60% forward overlap

Flight lines were drawn on partial and full-frame color-infrared film enlargements (40-by-40-inch or 1.02-meter format) and also black-and-white full-frame enlargements produced by EMSL-LV from NASA high-altitude aerial photography acquired prior to the low-altitude data collection. (For a more detailed breakdown of flights flown for the Western Energy Project, see the "Western Energy/Environment Monitoring Atlas", EPA 600/7-77-047a published in May, 1977).

These photographic enlargements, annotated with required flight lines, were placed in a pilot's package, which included other items, such as start/stop coordinates (latitude-longitude) for the flight lines, and topographic maps showing various recognizable land surface features. The pilots used the information contained in the packet to program the flight schedule. All aircraft data were collected by the Data Acquisition System on board NASA/Johnson Space Center's NP3A aircraft. After aircraft data collection was completed for each mine site, the film was processed by EMSL-LV and duplicate positive transparencies and prints were supplied to ERL for their analysis. The MSS data were processed at ERL. (See Appendix A for description of data acquisition systems).

Figure 1. Locations of Mine Sites Surveyed in the NASA/ERL Phase I Operation.

GROUND TRUTH

The color-infrared enlargements were also used as a base from which training sample sites were chosen. A training sample site is an area of the Earth's surface which appears to be homogeneous in composition when observed from above. Examples include a coal seam, a revegetation plot, etc. Such areas are subsequently used to "train" the computer to recognize these and/or similar land-cover categories, hence the term "training" sample site. Each training sample site was chosen and located on the color-infrared enlargements, and assigned a consecutive number or code. Prints of these aerial photographs were taken into the field for the ground truth operation. (See Appendix B for details of selecting training samples.)

SECTION 5

DATA REDUCTION AND PROCESSING PROCEDURES

PROCEDURES FOR AIRCRAFT MULTISPECTRAL SCANNER DATA

Processing of the aircraft MSS data was accomplished through task-designed software modules on the Data Analysis System (DAS) (Figure 2). These modules are linked in such a manner that output from one module serves as input to another. However, each module can be composed of several software programs that accomplish one major task. Figure 3 illustrates a simplified flow diagram which outlines the reduction and processing of data from an aircraft multispectral scanner. There are only minor differences in processing aircraft MSS data and Landsat MSS data.

Following data acquisition, the MSS data are decommutated and reformatted. The decommutation/reformatting process converts the PCM (Pulse-Code Modulation) format of the original aircraft data into a digital format compatible with the computer system. The digital tape that is produced by the decommutation/reformatting procedure is checked for data anomalies such as, sun angle manifestations, missing data, recording problems, etc. Most anomalies can be rectified by the application of software programs in the pre-processing and transformation block as seen in Figure 3. A data quality check can be performed by analyzing a hardcopy product (resulting from intermediate processing) or viewing the data on the Interactive Display System.

In the Pattern Recognition Modules a classification of the data set is initiated.

The supervised approach to pattern recognition requires that the analyst know something about the scene, because he is responsible for "training" the computer to recognize the various land-cover categories that are of interest. This is accomplished by outlining areas with known physical characteristics and then by computing statistics (means, variance, correlation matrix, etc.) for each training sample and grouping the samples into land-cover classes. (For details, see Appendix B).

The Pattern Recognition Modules were written to accommodate a maximum of 4 channels of digital data; therefore, it is necessary to run the Channel Selection Program to determine the 4 best channels for use in classifying each data set. Once the 4 channels have been determined, the analyst can begin classifying the data, using the approach described in Appendix B.

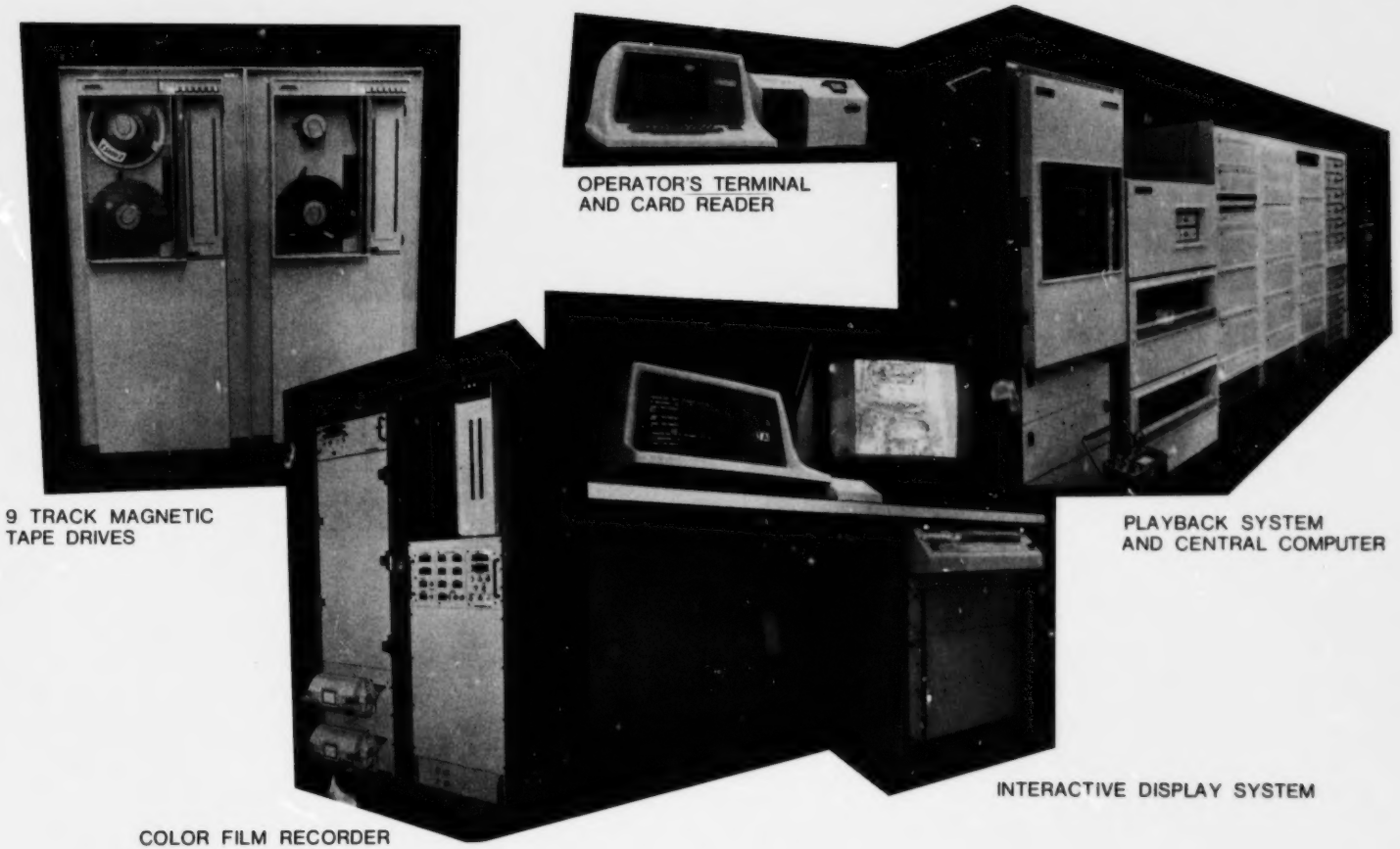

Figure 2. Data Analysis System (DAS).

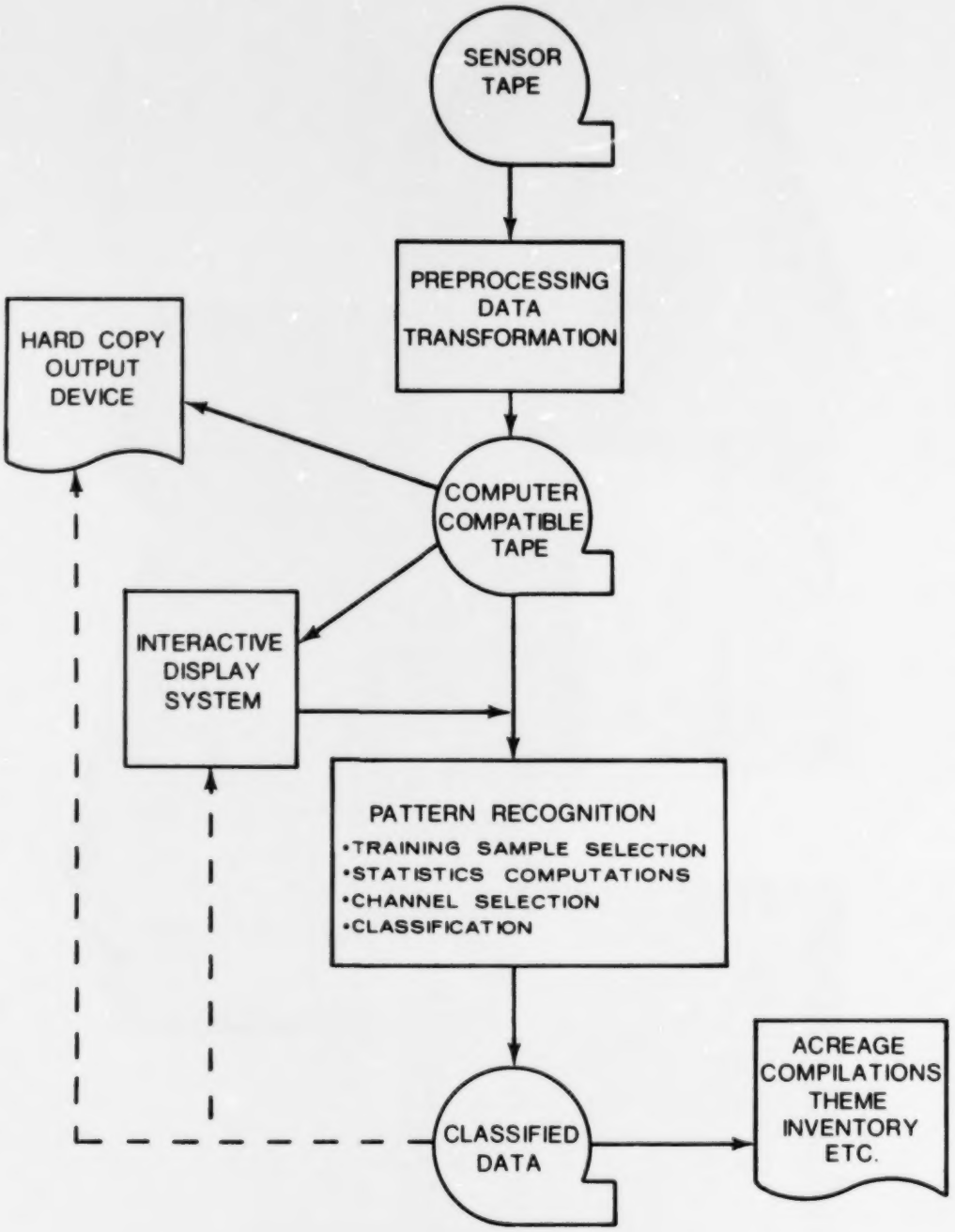

Figure 3. Multispectral Scanner Data Reduction and Processing Flow (Simplified).

CONVENTIONAL ANALYSIS PROCEDURES

Interpretation of aerial photography is a well-developed art. Experienced photo-interpreters can detect and identify man-made and natural features of the Earth's surface by means of shape, form, color, texture, pattern, and shadow. Objects can also be detected by indirect means, such as deducting their presence from the recognition of objects with which they are normally associated.

The photo analysis of the coal strip mine aerial photography was performed using a zoom-stereomicroscope, a light table, and the classification hierarchy developed by EMSL-LV personnel for analysis of coal strip mining areas (Table 1). First, appropriate stereo-pairs of each coal strip mine were located within the roll of duplicate positive transparencies. Next, transparent overlay material was placed over one of the frames of imagery, and the features of interest were outlined and annotated on this overlay. When the frame of imagery was completely interpreted, the overlay was sent to the Cartographic Laboratory for scribing. Scribing produces a "clean" product, e.g., lines are of equal width, numbers are the same size, etc.

TABLE 1. LAND-COVER CLASSIFICATION HIERARCHY FOR COAL STRIP MINE MONITORING

00 - Active Mine Features

- 01 - Advance cut
- 02 - Topsoil stockpile including embankment
- 03 - Stripping bench, high wall, open cut, pit, and related features
- 04 - Exposed coal seam
- 05 - Raw spoil bank and/or sideslope
- 06 - Coal storage pile
- 07 - Recontoured spoil
- 08 - Haul road including cuts, fills, turnouts, etc.
- 09 - Misc. disturbed areas within active mine complex

10 - Barren Land

- 14 - Shorelines, river banks
- 15 - Badlands (barren silts and clays, related metamorphic rocks)
- 18 - Man-made barrens

20 - Water Resources

- 21 - Settling ponds
- 22 - Pit ponds
- 23 - Undifferentiated ponds, lakes, and reservoirs
- 24 - Water courses, including canals

30 - Natural Vegetation

- 31 - Herbaceous types
- 32 - Shrub/scrub types
- 33 - Savanna-like types
- 34 - Forest and woodland types

40 - Cultural Vegetation (plantations and seedings)

Numerators

- 41 - Grass/forb seedings
- 42 - Tree/grass or tree/scrub plantations
- 45 - Seeding trails and test plots

(Continued on next page)

TABLE 1 (Continued)

Denominators

A - Vegetative cover 80 - 100%
B - Vegetative cover 60 - 80%
C - Vegetative cover 30 - 60%
D - Vegetative cover 5 - 30%
E - New seeding, vegetative cover less than 5%

1 - Production level better than native level
2 - Production level about equal with native level
3 - Production level less than native level

50 - Agricultural Production

51 - Field crops
56 - Fallow land

60 - Urban/Industrial

61 - Residential
62 - Commercial and services
63 - Institutional
64 - Industrial
65 - Transportation, communications and utilities
66 - Resource extraction

SECTION 6

RESULTS OF THE PHASE I OPERATIONS

Phase I operations for the first 18 months have been concluded and all of the specific objectives have been addressed by ERL and/or EMSL-LV. For convenience, the specific objectives are listed below:

- Transfer the data analysis system and its associated software technology and maintenance requirements technology to EMSL-LV
- Perform automated analysis of aircraft MSS data and manual classification of photographic data over selected coal strip mine sites
- Determine the utility of Landsat MSS Data for performing a Regional Land-Cover Classification of a portion of the Powder River Basin
- Compare the results obtained from the aircraft MSS Classification with the photo-interpretation results

TECHNOLOGY TRANSFER TO THE ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY-LAS VEGAS

The first objective was accomplished in two separate stages. Stage 1, a technology transfer session for EMSL-LV personnel, was conducted at ERL during the second week in October and again during the first week in December (1976). Both sessions lasted 3 weeks. During the first session, EMSL-LV personnel attended lectures which detailed the software and hardware aspects of the system and processed canned data sets under ERL contractor supervision. Session 2 began with a 3-day review and refamiliarization of the system. The remaining 12 days were used to perform a supervised classification of a strip mine data set. This task included all the reformatting steps in the data reduction and processing flow required to produce a hardcopy color print of the classification results.

Stage 2 was completed in January of 1977 when personnel from ERL delivered, setup, and performed the necessary tests to make the EMSL-LV DAS a separate and operational system.

AUTOMATED AND MANUAL ANALYSIS OF AIRCRAFT-ACQUIRED DATA OVER SELECTED COAL STRIP MINES

To accomplish this objective, ERL personnel processed aircraft-acquired MSS data over selected coal strip mines or lease areas while EMSL-LV personnel analyzed the aerial photography corresponding to the MSS coverage. Four MSS data sets, one mine per set, were acceptable in data quality. Four additional data sets were not accepted due to tape recorder or scan angle/sun angle problems. The results of the supervised classification approach, photo-interpretations, and descriptive information about the mines are presented on the following pages.

BELLE AYR COAL STRIP MINE

The Belle Ayr Mine is located near Gillette (Campbell County), Wyoming, (the extreme northeastern corner of the state). Belle Ayr is operated by AMAX Coal Company and produces over 275,000 tons of coal per month. This coal is transported to the Public Service Companies of Pueblo, Denver, and Boulder, Colorado, and the Kansas City Power and Light Company of Burlington, Iowa.

Vegetation of this area is of the sagebrush-steppe type. This vegetation type is dominated by sagebrush in open grassland containing wheatgrasses, needle-grasses and needle-and-threadgrasses on silt to silty clay-loam soils. (See Appendix C for scientific names of vegetation types). This type occurs in northeastern Wyoming and most of the major species have moderately good suitability for rehabiliation, but are relatively unavailable for that purpose.

Eight channels of aircraft-acquired MSS data were decommutated/reformatted, and a subset of the four best channels was used to generate the classification maps (Figure 4 and Figure 5). The supervised approach to automatic data processing of MSS data was used for the Belle Ayr Mine MSS data set. Figure 6 presents the results of the EMSL-LV photo-interpretation of approximately the same area. The classification hierarchy for this photo analysis is presented in Table 1 (located in Section 5 of this report).

To facilitate an image-to-image evaluation of the results, the analyst conducted two computer runs to separate mine-related from non-mine-related classes as seen in Tables 2 and 3. In general, the classification of non-mine-related features agreed with the photo-interpreted results and ground checks. Note the olive green area in the bottom right hand portion of the image and how it compares with the photo results. Note also, the amount and location of bare soil areas on each image. Even the diverted Caballo Creek is classified. Finally, note the distribution of the natural vegetation and how the classified image compares with the photo analysis. The classification of the mine-related features also agreed with the photo-interpreted results and ground checks. Note the identification of the buildings comprising the mine facility (white area) and the areal extent of the active mining pit. Finally note, in the upper portion of the image, the sharply defined "advance-cut" areas.

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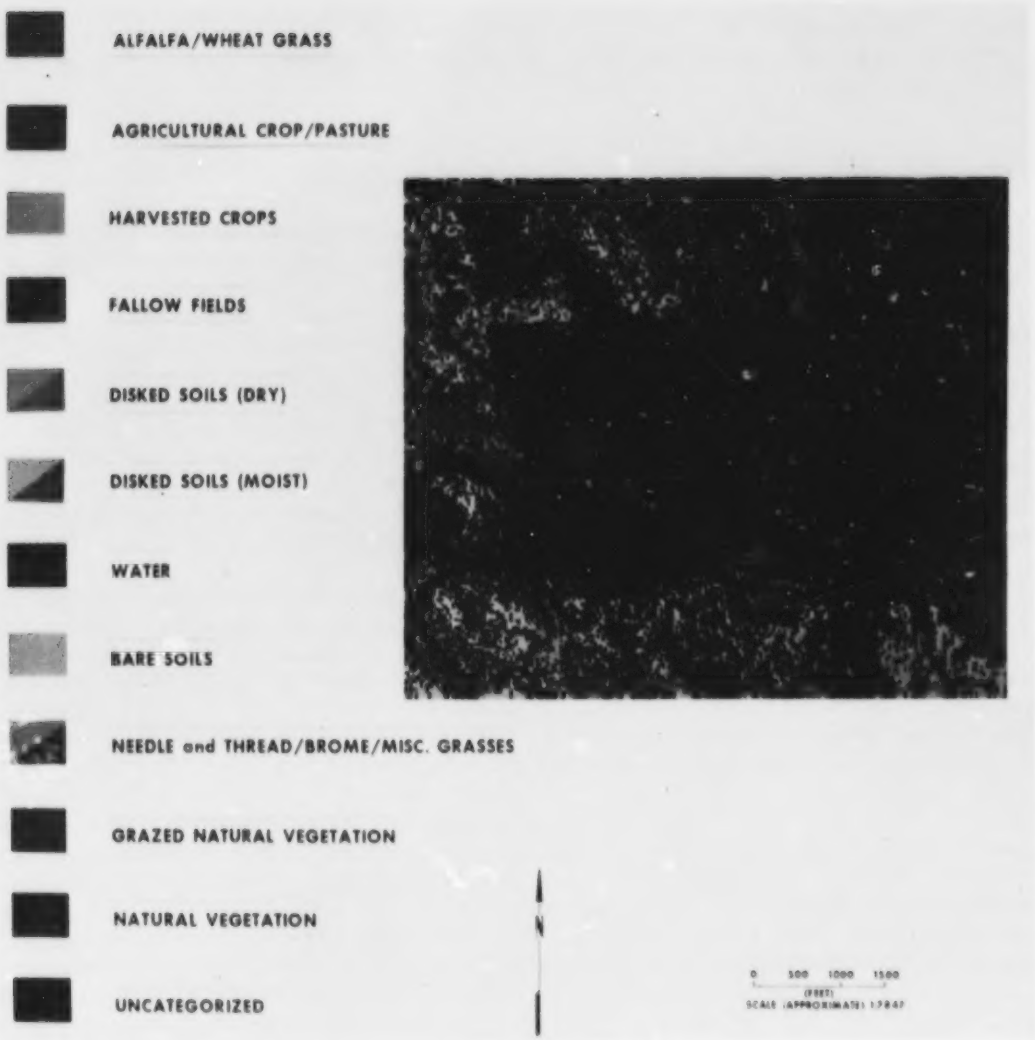

Figure 4. Classification Results (Non-Mine Related Classes) for the Belle Ayr Coal Strip Mine, Campbell County, Wyoming.

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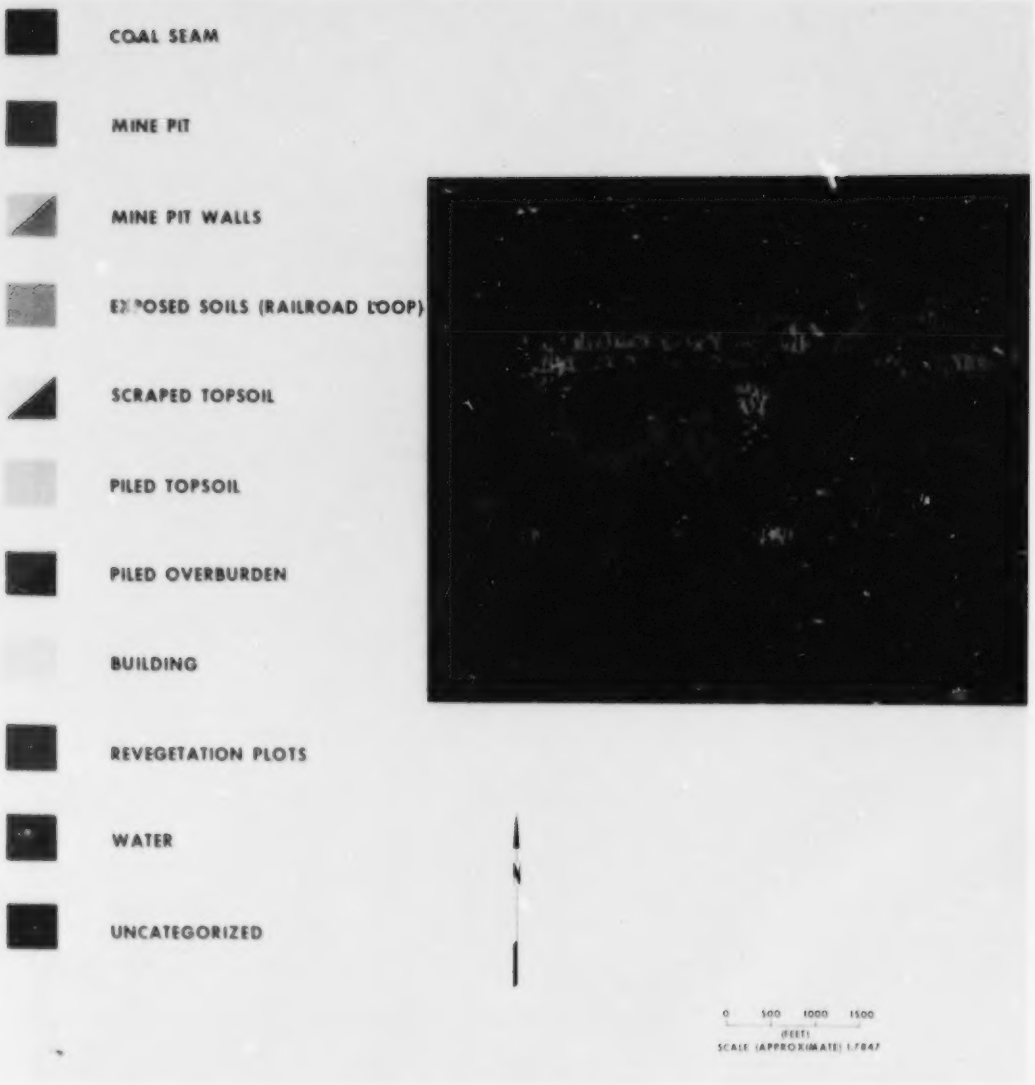

Figure 5. Classification Results (Mine-Related Classes) for the Belle Ayr Coal Strip Mine, Campbell County, Wyoming.

Figure 6. Photo-Interpreted Land-Cover Map of the Belle Ayr Coal Strip Mine. (See Table 1 for a key to EMSL-LV Land-Cover numbering system.)

TABLE 2. ACREAGE STATISTICS FOR MINE-RELATED CLASSES DERIVED FROM AIRCRAFT-ACQUIRED MSS DATA FOR THE BELLE AYR COAL STRIP MINE

Class Name	Acres
Coal Seam	11
Mine Pit	19
Mine Pit Walls	21
Exposed Soils (Railroad Loop)	20
Scraped Topsoil	47
Piled Topsoil	13
Piled Overburden	9
Building	41
Revegetation Plots	4
Water	2
Uncategorized *	797

* Includes non-mine-related classes on P. 20

TABLE 3. ACREAGE STATISTICS FOR NON-MINE-RELATED CLASSES DERIVED FROM AIRCRAFT-ACQUIRED MSS DATA FOR THE BELLE AYR COAL STRIP MINE

Class Name	Acres
Alfalfa/Wheat grasses	4
Agricultural Crop	8
Pasture	1
Harvested Crops	1
Fallow Fields	15
Disked Soils (Dry)	3
Disked Soils (Moist)	41
Water	77
Bare Soils	155
Grazed Natural Vegetation	18
Natural Vegetation	55
Uncategorized *	606

* Includes mine-related classes on P. 19

BLACK MESA COAL STRIP MINE

The Black Mesa Coal Strip Mine is located in the northeastern corner of the State of Arizona, in Navajo and Apache counties. It is operated by Peabody Coal Company headquartered in St. Louis, Missouri. Black Mesa is in the 500,000-and-over tonnage class and strips in excess of 20,000 tons per day. The total tonnage mined in 1974 (which is the last year statistics are available) was 3,933,493 tons. Coal from this mine is transported via pipeline to power plants outside the local area. Average elevation on the lease area is approximately 6,500 feet (1,980 meters), placing it in the pinyon pine/juniper vegetation zone.

Dominant vegetation types within the lease area are:

Pinyon Pine	Snakeweed
Juniper	Sagebrush
Alkali Sacatone	Blue Gramma
Greasewood	Winterfat
Rabbit Brush	

Eight channels of data were also decommutated and reformatted for this mine and the four best channel subset was used in generating the classification map (Figure 7). For comparative purposes, the photo-interpreted image is presented in Figure 8. Note the amount of detail that was produced from classifying the digital data, e.g., revegetated areas (red on the classified image) and the relative distribution of the pinyon/juniper association. Also, note how well the location and distribution of the piled overburden on the two images compare. The acreage software program available on the DAS eliminates the need to perform dot counts or use of a planimeter to calculate acreages. Table 4 was developed through the use of such software and is reasonably accurate when all input parameters are known and entered correctly.

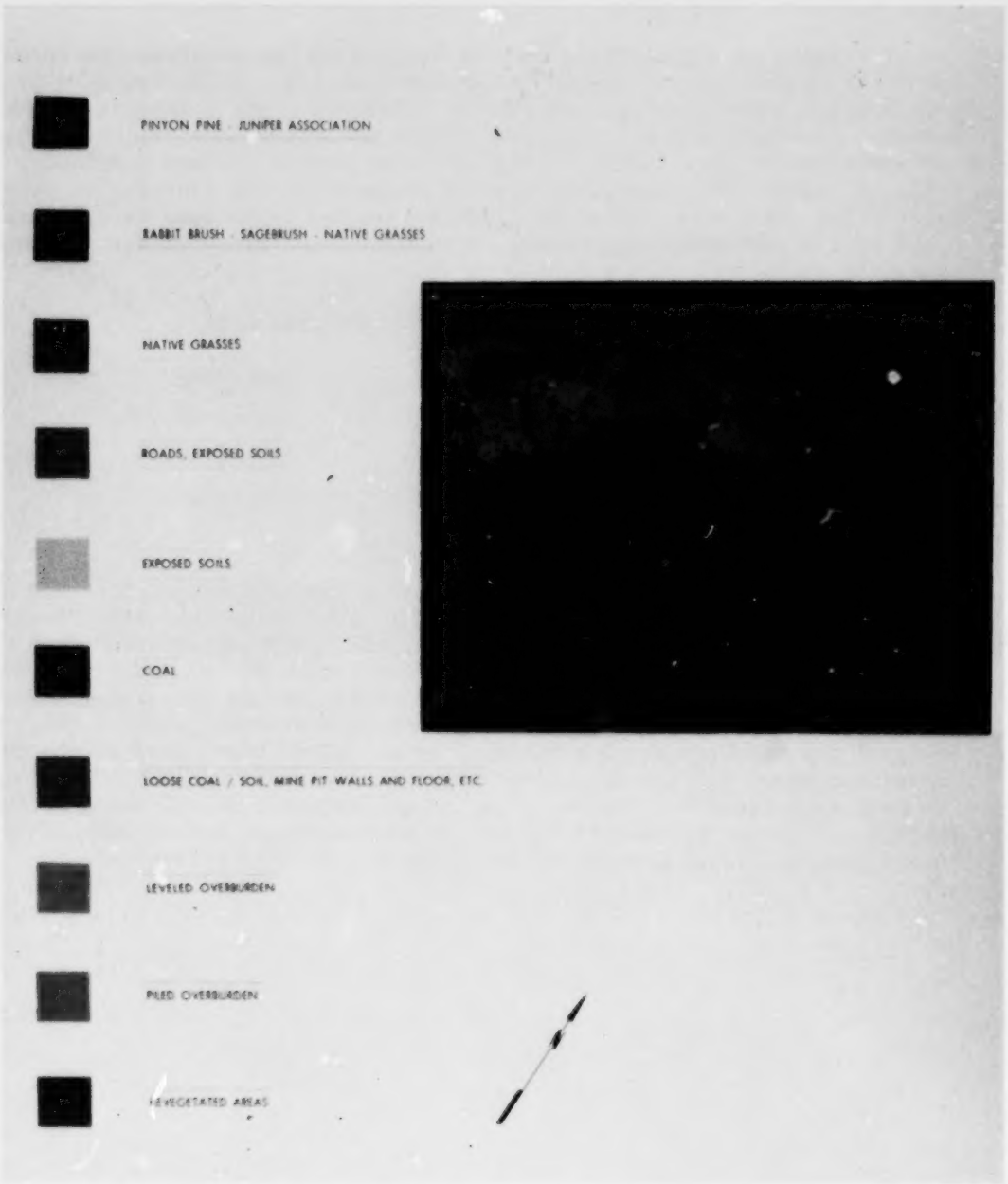

Figure 7. Color-Coded Land-Cover Classification Map of Aircraft-Acquired MSS Data for the Black Mesa Coal Strip Mine.

Figure 8. Photo-Interpreted Land-Cover Map of the Black Mesa Coal Strip Mine. (See Table 1 for a key to EMSL-LV land-cover numbering system.)

TABLE 4. ACREAGE STATISTICS DERIVED FROM THE AIRCRAFT-ACQUIRED MSS DATA FOR THE BLACK MESA COAL STRIP MINE

Land Cover Category	Acres
Natural Vegetation:	
Pinyon Pine/Juniper	584
Rabbit Brush/Sagebrush/Native Grass	1,234
Active Mine Features:	
Roads, Exposed Soils	238
Exposed Soils	4
Coal	52
Loose Coal, Mine Pit, Coal-Covered Soil	81
Leveled Overburden	200
Piled Overburden	122
Revegetated Areas	172

DAVE JOHNSTON COAL STRIP MINE

The Dave Johnson Coal Strip Mine is located in the north-east central portion of the State of Wyoming in Converse County. The Dave Johnston Mine is operated by Pacific Power and Light Company and is termed a "captive mine" because it ships coal by rail to the Dave Johnson Power Plant located in nearby Glenrock, Wyoming.

The mine has two coal seams that are being mined at the present time. The youngest, the Badger seam, is approximately 16 feet in thickness, and the oldest, the School seam, is roughly 37 feet in thickness. The average depth of the active pit is about 140 feet with a maximum depth of approximately 180 feet.

Vegetation is of the short-grass prairie type. This type primarily occurs on dry prairies on shallow soils in southeastern Montana and northeastern Wyoming. Dominant species are gramma wheatgrasses and various needlegrasses. The species that characterize this type have moderately poor suitability and fair availability for rehabilitation.

Aircraft-acquired MSS data were processed in the same manner as the data from the previous mines. Processing results for this mine, based on field-verified training samples, produced a classification map which contained about 60 percent uncategorized data. Using the aerial photography as a source, samples were selected for ground-cover types that were uncategorized, and the classification was re-run. However, 2.7% of the data which were scattered over small unrelated areas remained uncategorized (black areas on the classified image). This indicated that, in terms of land-cover classes, no real deficiency existed. A visual examination of the classified mine scene indicates that general land-cover categories were classified reasonably well, including both mine-related features and surrounding natural land-cover types. Figure 9 depicts the computer classification results and Table 5 summarizes the acreage computed for each class. Photo-interpretation results are presented in Figures 10 and 11.

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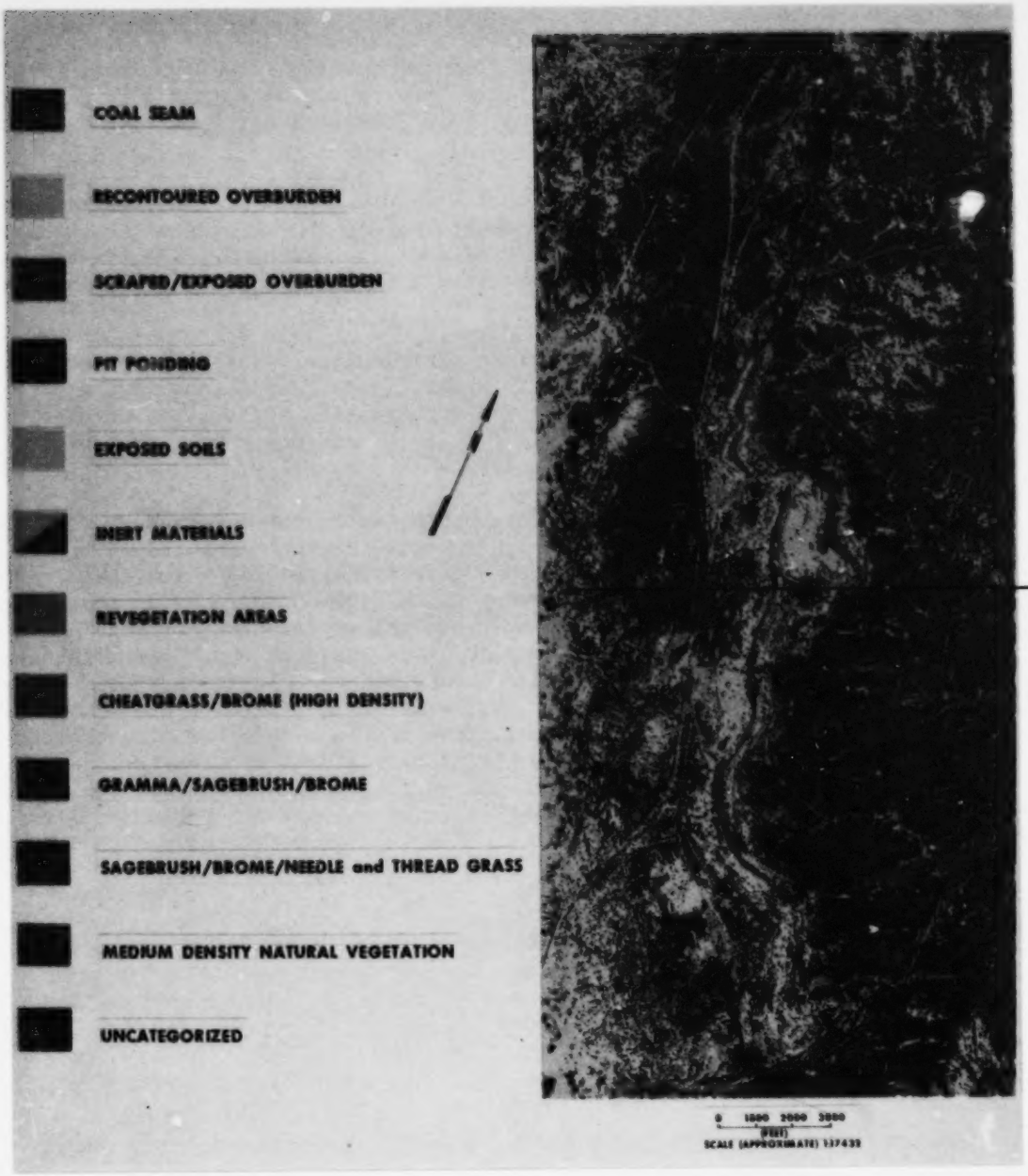

Figure 9. Color-Coded Land-Cover Classification Map of Aircraft-Acquired MSS Data for the Dave Johnston Coal Strip Mine, Converse County, Wyoming.

Figure 10. Photo-Interpreted Land-Cover Map of the Dave Johnston Coal Strip Mine, Section A. (See Table 1 for a key to EMSL-LV land-cover hierarchy system.)

Figure 11. Photo-Interpreted Land-Cover Map of the Dave Johnston Coal Strip Mine, Section B. (See Table 1 for a key to EMSL-LV land-cover hierarchy system.)

TABLE 5. ACREAGE STATISTICS DERIVED FROM AIRCRAFT-ACQUIRED MSS DATA FOR THE DAVE JOHNSTON COAL STRIP MINE

Class Name	Acres
Coal Seam	116
Recontoured Spoils	481
Scraped/Exposed Overburden	83
Pit Ponds	11
Exposed Soils	1,907
Inert Materials	315
Revegetation	504
Cheatgrass/Brome (High Density)	291
Gramma/Sagebrush/Brome	2,369
Sagebrush/Brome/Needle and Threadgrasses	2,213
Medium Density Natural Vegetation	642
Uncategorized	247

NAVAJO COAL STRIP MINE

The Navajo Mine is located in San Juan County, New Mexico, in the extreme northwestern corner of the State. The mine is also located in the largest and best known coal field in the San Juan Basin, the Navajo field, which extends about 35 miles from the San Juan River southward along and to the east of the outcrop of the Fruitland formation. The Navajo Mine is operated by Utah International, which holds the leases for the northern two-thirds of the field while El Paso Natural Gas Company holds the southern leases.

The coal is subbituminous B to A rank with a slight decrease in quality southward owing to an increase in ash content. In 1974, this mine produced 6,955,000 tons of coal. The preceeding year, it produced over 7.3 million tons.

Vegetation in the San Juan Basin is limited to those species found in grassland associations. There is a considerable amount of the various grama species, galleta, snakeweed, sacatone and Mormon tea within the lease area of the mine. This is by far, the longest mine studied in Phase I.

The same processing procedures were used to select a subset of four channels for use in supervised classification runs. The results of the 62-category classification are presented in Figure 12. This classification required 6.5 hours of computer processing time. These 62 categories had to be merged into 6 broad classes that correspond to Level I of the hierarchy in Table 1.

For comparative purposes, the photo-interpreted images are presented in Figures 13 through 16. Note in Figure 16 the branching of the San Juan River at the top of the photo and how it was resolved and classified on the digital data set. Also, note, the amount and extent of the recontoured areas on the photo-interpreted images and how well they correspond with the classified images. Table 6 summarizes the results of the classification. By far the greatest number of acres fall into the natural vegetation class. The general category of mine-related features ranks second in size.

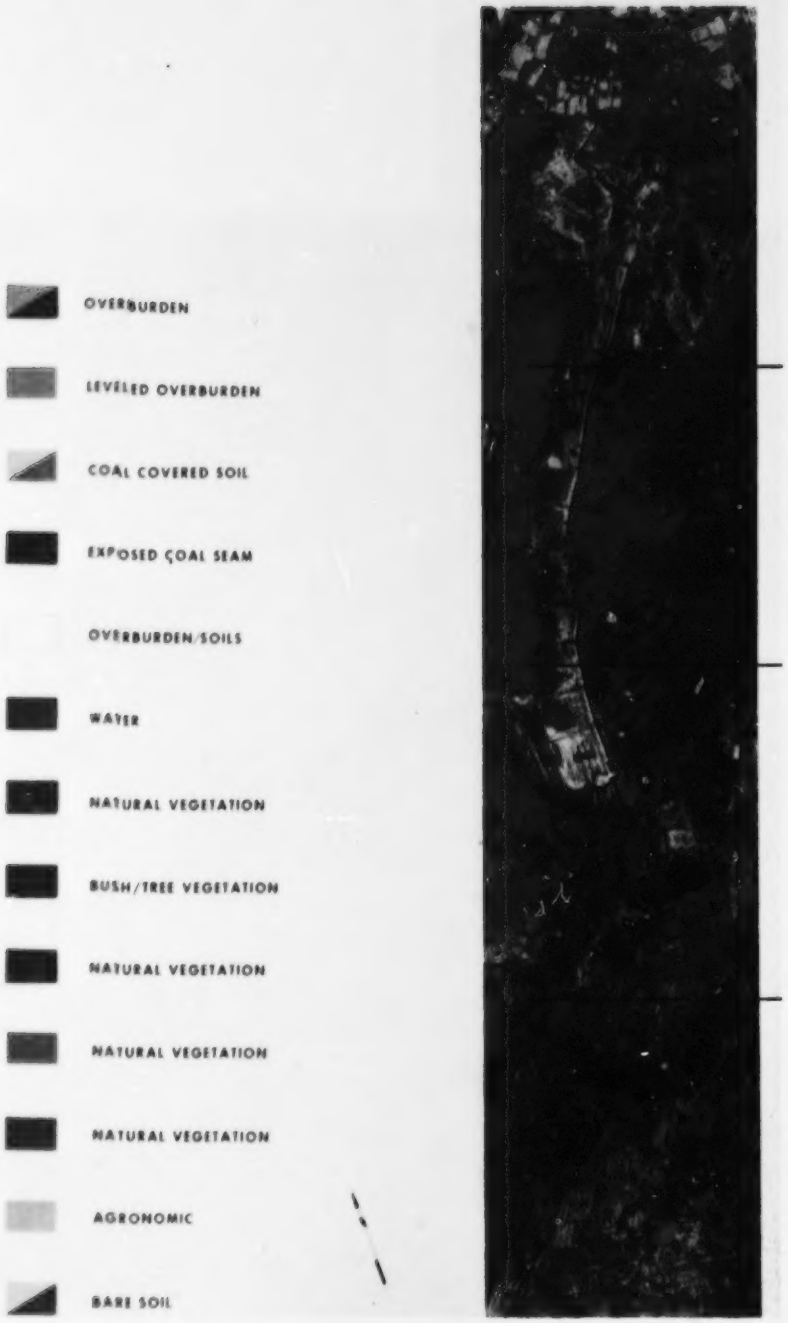

Figure 12. Color-Coded Land-Cover Classification Map of Aircraft-Acquired MSS Data for the Navajo Coal Strip Mine.

Figure 13. Photo-Interpreted Land-Cover Map of the Navajo Coal Strip Mine, Section A. (See Table 1 for a key to EMSL-LV land-cover hierarchy system.)

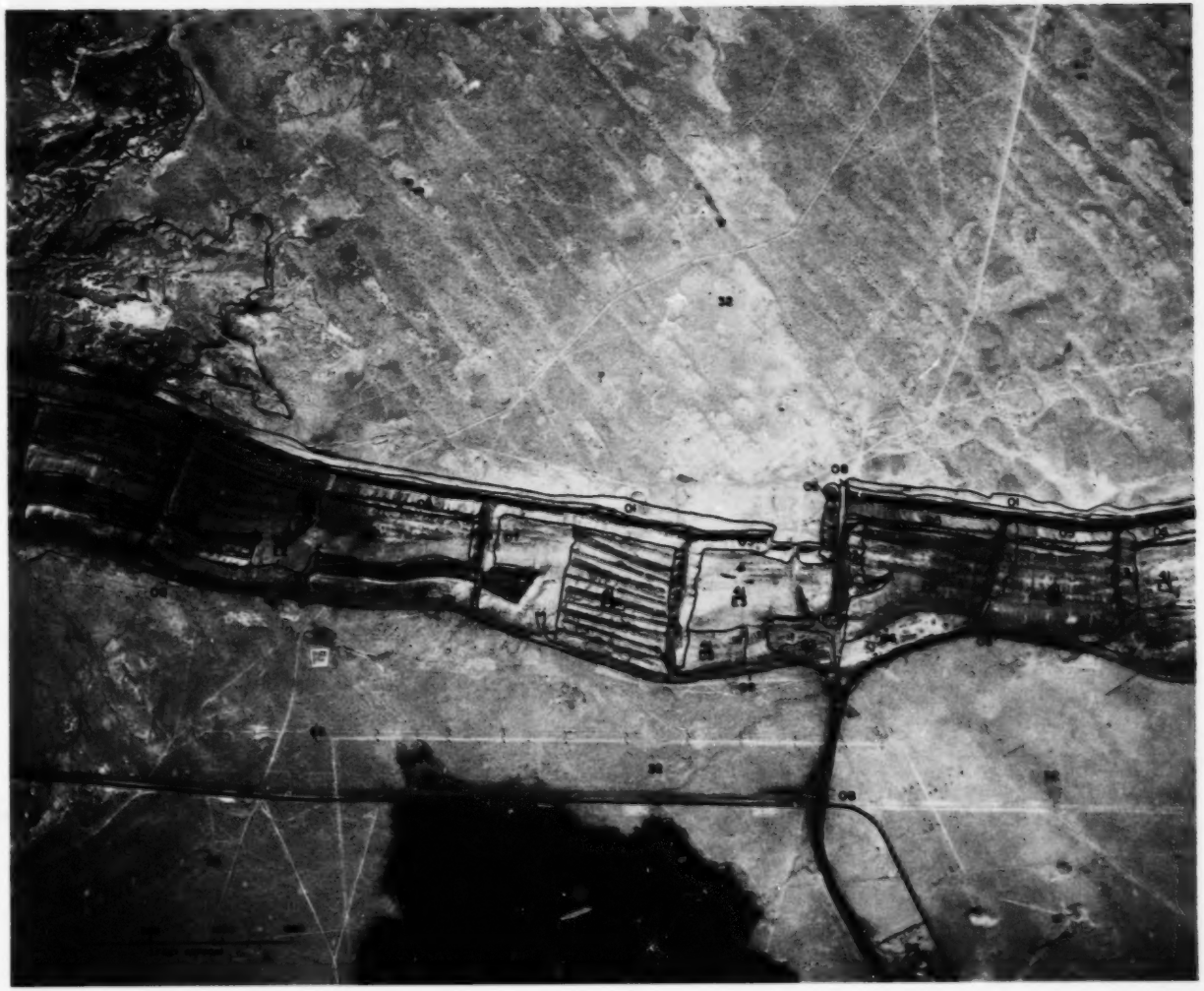

Figure 14. Photo-Interpreted Land-Cover Map of the Navajo Coal Strip Mine, Section B. (See Table 1 for a key to EMSL-LV land-cover hierarchy system.)

Figure 15. Photo-Interpreted Land-Cover Map of the Navajo Coal Strip Mine, Section C. (See Table 1 for a key to EMSL-LV land-cover hierarchy system.)

Figure 16. Photo-Interpreted Land-Cover Map of the Navajo Coal Strip Mine, Section D. (See Table 1 for a key to EMSL-LV land-cover hierarchy system.)

TABLE 6. ACREAGES DERIVED FROM AIRCRAFT-ACQUIRED MSS DATA FOR THE NAVAJO COAL STRIP MINE

Class	Acres
Water	94
Agronomic	1,780
Natural Vegetation	11,449
Mine-Related:	
Coal	238
Overburden	1,853
Coal-Covered Soils, Haul Roads, Exposed Soils	866

REGIONAL APPLICATION OF LANDSAT MULTISPECTRAL SCANNER DATA

The use of Landsat data was incorporated into Phase I of this project to gain insight into approaches and techniques for producing land-cover classifications which are suited to regional monitoring and analysis of energy-related activities.

Several features associated with Landsat digital data serve to enhance the use of such data for the "regional" type of analysis. First, costs associated with computer processing of data covering large areas are relatively low when compared to the corresponding aircraft data-derived cost figures. Second, since the satellite system has a regular, established coverage date, repetitive coverage for change detection is possible. And finally, the data can be registered (matched) to map coordinates, which permits the integration of non-satellite ancillary information, e.g., soil type, elevation, geology, etc., via digitizing apparatus.

The area, selected for this study, approximately 1 degree of latitude by 1 degree of longitude, was outlined on the Gillette 1:250,000 quadrangle. This area was selected becuase of the presence of a vast number of active coal strip mining operations in the alluvial valley of the Powder River Basin.

Both a "supervised" approach as previously described, and an "unsupervised" approach were used in data processing. The unsupervised approach differs from the supervised approach mainly in that every element of data is examined by the computer for inclusion in or initiation of a land-cover class. In the unsupervised approach, the investigator can set several statistical limits in such a manner that signatures are developed for a large number of spectral classes. In the supervised approach, the classes are limited to those land-cover categories for which training samples were selected. Ground truth data were not acquired specifically for processing Landsat multispectral scanner data. Therefore, the same training sample sites that had been verified in the immediate vicinity of a mine during the summer missions of 1976 were used. Computer-compatible tapes corresponding to Landsat Scene 5415-16333 (June 7, 1976) were selected and processed.

The land-cover classification was geographically rectified to the Universal Transverse Mercator projection, scaled to 1:250,000 and placed on that section of the Gillette quadrangle corresponding to the 1 degree latitude by 1 degree longitude area of interest. The resulting map product was photographically reduced for inclusion in this report (Figure 17). An acreage compilation by land-cover category is shown in Table 7. The results obtained appear to correspond closely to major land-cover patterns known to exist in the area. Individual mine sites are detectable when colors are assigned to the combined classes of exposed coal seams, exposed soil and overburden, and exposed topsoil.

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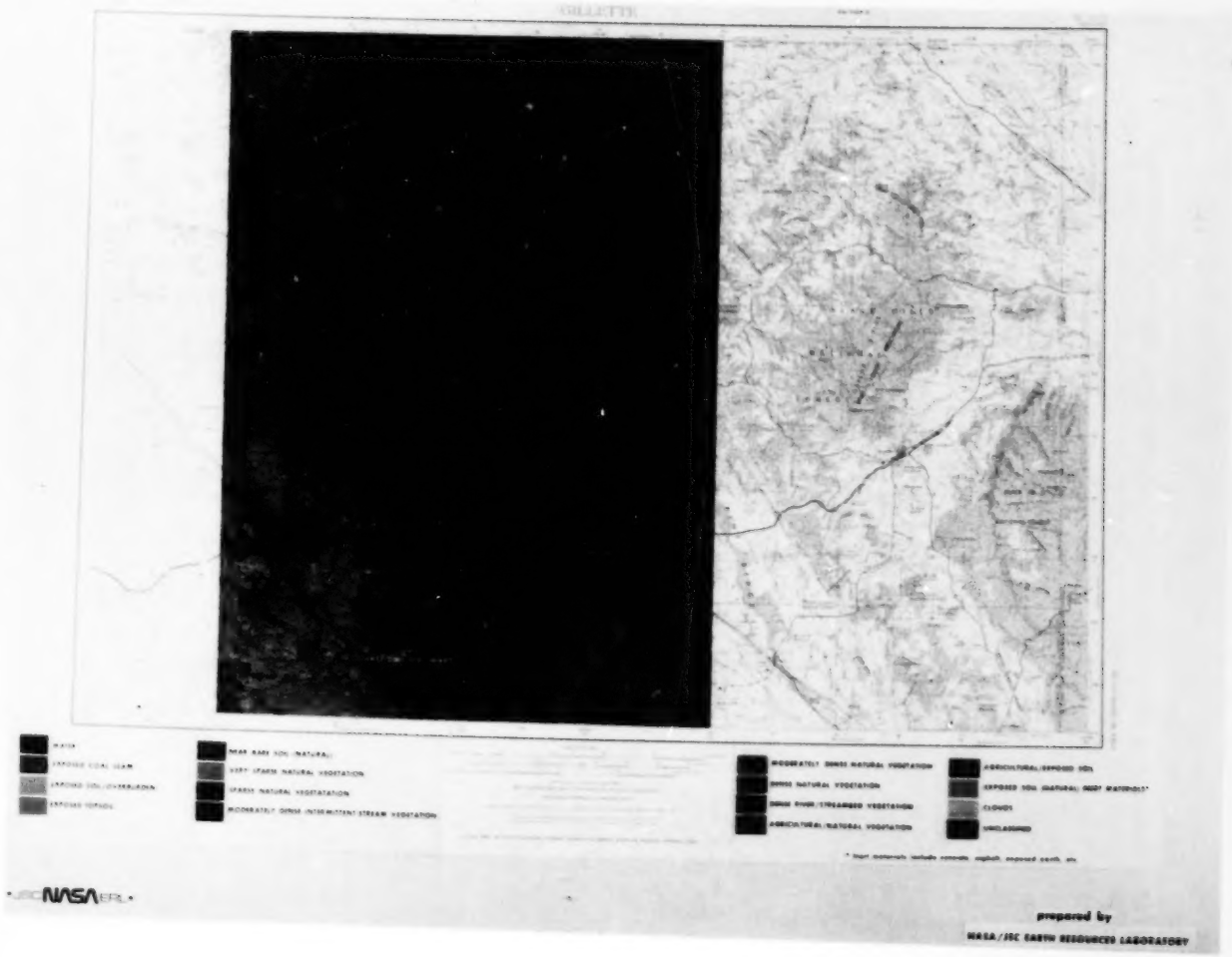

Figure 17. Landsat Land-Cover Classification of Powder River Basin Area, Wyoming.

TABLE 7. ACREAGE STATISTICS FOR THE NASA/ERL LANDSAT CLASSIFICATION

Land-Cover Category	Acres
Water	6,152
Exposed Coal Seam	500
Exposed Soil/Overburden	22,108
Exposed Topsoil	3,047
Near Bare Soil (Natural)	82,161
Very Sparse Natural Vegetation	563,397
Sparse Natural Vegetation	276,822
Moderately Dense Intermittent Stream Vegetation	259,233
Moderately Dense Natural Vegetation	620,073
Dense Natural Vegetation	679,079
Dense River/Streambed Vegetation	21,839
Agricultural/Natural Vegetation	163,132
Agricultural/Exposed Soil	70,091
Exposed Soil (Natural) Inert Materials	29,183
Clouds/Cloud Shadows	1,650
Uncategorized	43,171

COMPARATIVE ANALYSIS OF THE AUTOMATED AND MANUAL CLASSIFICATION RESULTS

In order to assess the overall value of our classified multispectral products, a decision was made to compare them with the photo-interpretation results. It was fully understood that the photo-interpreted data are not absolute, but the process does take into account various parameters/indicators that a computer cannot consider because of programming limitations.

The photo-interpreted aerial photographs, simultaneously acquired with the multispectral scanner data were used as the reference for the evaluation of each class. Random check points on the photography were selected and then located on the computer-derived land-cover classification map. A running total of points, agreement vs. disagreement per class, was recorded for each mine the the chi-square value was then computed.

According to MacDonald (1966), a measure of the discrepancy existing between a set of "k" observed frequencies (0_1, $0_2 \ldots 0_k$) and a corresponding set of "k" expected frequencies (e_1, $e_2 \ldots e_k$) is given by:

$$\frac{(0_1 - e_1)^2}{e_1} + \frac{(0_2 - e_2)^2}{e_2} + \ldots \frac{(0_k - e_k)^2}{e_k} = \sum_{i=1}^{k} \frac{(0_i - e_i)^2}{e_i}$$

where:

0_i = ith observed frequency

e_i = ith expected frequency

If χ^2 (as calculated from the above equation) is equal to zero, observed and expected frequencies agree exactly; if χ^2 is greater than the critical value in the χ^2 table, a discrepancy exists. The larger the difference between χ^2 and the critical value (assuming $\chi^2 >$ critical value), the greater the discrepancy between the observed and expected frequencies. If χ^2 is found to be larger in magnitude than the critical value, the null hypothesis being tested (i.e. a discrepancy exists) must be rejected, and it is therefore concluded there is no significant difference between observed and expected frequencies (i.e. the alternate hypothesis).

The following chi-square contingency tables and associated χ^2 values have been derived from data check points located (as previously mentioned) on the Black Mesa, Dave Johnston, Navajo, and Belle Ayr MSS data sets.

For the Black Mesa Mine (Table 8), the critical value $\chi^2_{.99}$ and $_{.95}$ for 8 degrees of freedom, is 20.1 and 15.5 respectively, and 7.86 (the calculated χ^2 value) <22.0 and 15.5. Hence, it is concluded that the photo-interpretation results at the 0.05 or at the 0.01 levels of significance are not significantly different from the MSS classification results.

TABLE 8. CHI-SQUARE CONTINGENCY TABLE (2 x 9) FOR THE BLACK MESA COAL STRIP MINE

Land Use Classification	32	41	07	32	04	05	08	41	33
Observed Frequency (MSS)	1	3	2	3	1	1	1	2	0
Expected Frequency (Photo)	3	3	3	3	3	3	3	3	3
$\chi^2 = 7.86$	V = 8 degrees of freedom								

TABLE 9. CHI-SQUARE CONTINGENCY TABLE (2 x 8) FOR THE DAVE JOHNSTON COAL STRIP MINE

Land Use Classification	32	41	07	33	04	08	22/23	09
Observed Frequency (MSS)	4	2	3	0	4	3	3	4
Expected Frequency (Photo)	5	5	5	1	5	5	4	5
$\chi^2 = 5.37$	V = 7 degrees of freedom							

TABLE 10. CHI-SQUARE CONTINGENCY TABLE (2 x 8) FOR THE NAVAJO COAL STRIP MINE

Land Use Classification	41	07	32	34	04/06	22/23	50	02/03/04/08
Observed Frequency (MSS)	1	2	6	2	2	3	4	4
Expected Frequency (Photo)	1	5	7	5	3	4	10	6
$\chi^2 = 9.54$	V = 7 degrees of freedom							

TABLE 11. CHI-SQUARE CONTINGENCY TABLE (2 x 8) FOR THE BELLE AYR COAL STRIP MINE

Land Use Classification	32	50	56	05/04/03	6	02	22/23	66
Observed Frequency (MSS)	5	0	0	3	1	2	1	2
Expected Frequency (Photo)	5	3	3	3	1	4	4	4
$\chi^2 = 10.25$	V = 7 degrees of freedom							

The critical value of $\chi^2_{.99}$ and $_{.95}$ at 7 degrees of freedom for the remaining mines (Tables 9, 10, and 11) is 18.5 and 14.1 respectively, and none of the computed χ^2 values are greater in magnitude than these critical values. Therefore, it is concluded that the observed automatic classification results do not differ significantly from the photo-interpreted aerial photographs at the 0.05 or at the 0.01 levels of significance.

SECTION 7

SUMMARY

Phase I operations for the Western Energy Overhead Monitoring Project were successfully completed. The Environmental Monitoring and Support Laboratory in Las Vegas, Nevada, received a Data Analysis System and its personnel were trained to operate and maintain the system.

Aerial photography and aircraft scanner data over selected coal strip mines in the Western United States were processed and analyzed to determine the feasibility of each for monitoring purposes. Also, Landsat MSS data were processed on the DAS to determine their utility in regional analysis of coal strip mining operations.

Finally, the results of the interpretation of aerial photography and the processed aircraft scanner data were compared to identify apparent weak areas in either approach and to determine if either approach was superior. The χ^2 (chi-square) test demonstrated that there were no significant differences in the results obtained using computer implemented techniques and those obtained using conventional aerial photo-interpretation techniques.

SECTION 8

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APPENDIX A

DATA ACQUISITION SYSTEMS

Effective application of data collected by the multispectral scanner or aerial camera is dependent upon understanding the instruments involved. Therefore, a brief discussion follows to familiarize the reader with both of these systems.

AIRBORNE MULTISPECTRAL SCANNER

The airborne multispectral scanner (MSS), Daedalus DS-1260, acquires data at altitudes ranging from 500 to 20,000 feet (152 to 6,000 meters) above ground level. This is an 11-band system designed to collect and record radiant energy in the ultraviolet through the thermal infrared portions of the electromagnetic spectrum (Table A-1). The scanner has a rotating mirror that scans across the ground scene, perpendicular to the line of flight (Figure A-1). Radiant energy from the ground surface is reflected through focusing optics to a beam splitter which diverts the short wavelength radiation (0.38 to 1.10 micrometers) to a 10-channel spectrometer and the thermal infrared radiation (8 to 14 micrometers) to a solid-state detector. Electronic signals from the 11 detectors are digitized and recorded as high density digital data on an analog magnetic tape. The MSS scan rate is synchronized to the aircraft ground speed and altitude, which results in scan-line contiguity at nadir, thereby avoiding over- or under-scanning the ground scene. The actual size (ground resolvable distance) of each element is a function of three factors: (1) aircraft altitude above target level; (2) scanner instantaneous field of view (measured in milliradians); and (3) scan angle (that angle, measured from the perpendicular, at which reflected electromagnetic radiation is being received as the scanning mirror rotates). The scanner is equipped with internal visible and thermal reference sources which provide information for calibration of the data. The aircraft sensor tape is processed on the ground-based DAS to display and create images of the surveyed scene.

AERIAL CAMERA

The camera used in the data acquisition phase of this study was a Wild-Heerbrugg RC-8 metric camera. The RC-8 camera is a medium focal length (6-inch), 9-inch square format sensor. Its primary use by NASA is as a ground coverage documenting camera with a gyroscopically stabilized mount. The film/filter combinations and exposure techniques were chosen to obtain

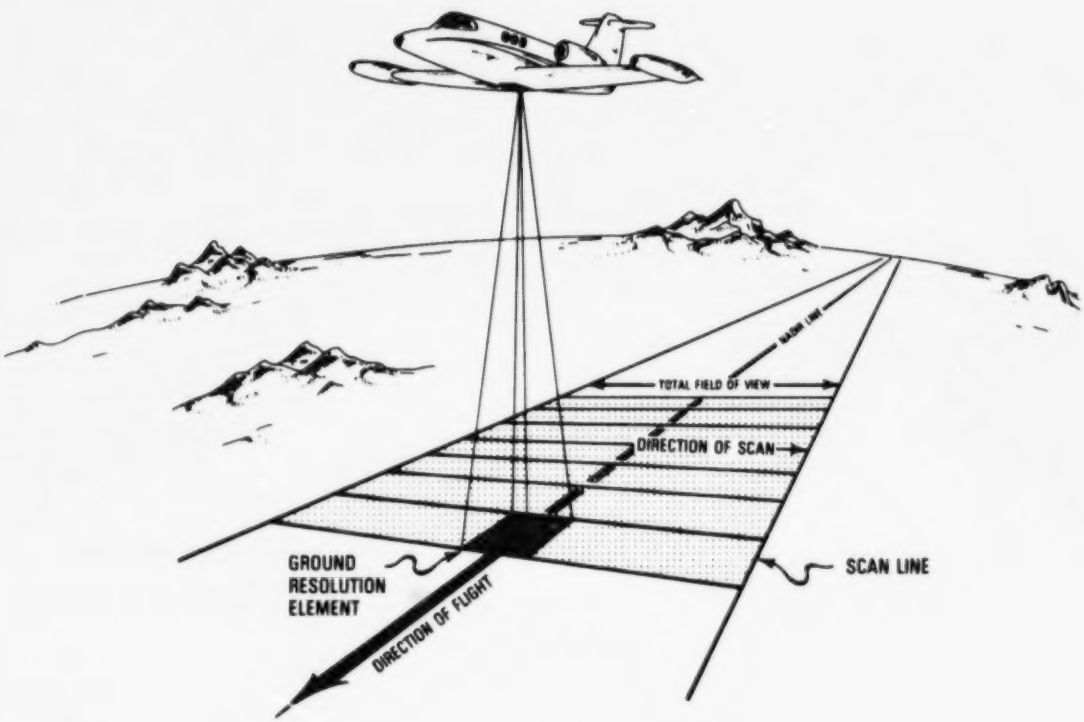

Figure A-1. Multispectral scanner imaging characteristics simplified

TABLE A-1. MULTISPECTRAL SCANNER WAVELENGTH BANDS

Channel	Wavelength Band (μm)	Color/Spectrum
1	0.38-0.42	Ultraviolet
2	0.42-0.45	Blue
3	0.45-0.50	Blue
4	0.50-0.55	Green
5	0.55-0.60	Green
6	0.60-0.65	Red
7	0.65-0.70	Red
8	0.70-0.79	Near Infrared
9	0.80-0.89	Near Infrared
10	0.92-1.10	Near Infrared
11	8.00-14.00	Thermal Infrared

photographic imagery in the desired spectra. Two cameras are available on board NASA's NP3-A aircraft and are usually selected to provide overlapping or contiguous simultaneous coverage using color, color-infrared, or black-and-white film.

The following lists the camera specifications:

Type	Square image (9-inch) using a 6-inch F/5.6 Universal Aviogon lens. Unit has no forward-motion compensation.
Lens	Focal lenght, 6-inch nominal, with Water-house stops; apertures of F/5.6, 6.8, 8, 11, 16, 22, and 32. View angle 74°.
Shutter	Continuous variable rotary; speed, from 1/100 to 1/700 second.
Cycle Interval	One cycle each 3.5 seconds, maximum rate.

LANDSAT MULTISPECTRAL SCANNER

NASA's Earth Resources Technology Satellite (ERTS) Program presently consists of two orbiting satellites, names Landsat-1 and Landsat-2, devoted solely to remote sensing of the Earth's surface. Each Landsat satellite operates in a circular, sun-synchronous, near-polar orbit at a constant altitude of 571 statute miles (919 kilometers). The orbital path of each satellite repreats every 18 days and the orbits of Landsat-1 and Landsat-2 are so synchronized that coverage over any point on Earth is repeated every 9 days.

The primary sensor on each satellite is the four-band MSS which collects spectral data reflected from the Earth's surface in two visible bands (0.5-0.6 micrometers and 0.6-0.7 micrometers) and two near-infrared bands (0.7-0.8 micrometers and 0.8-1.1 micrometers). The MSS is a line-scanning device which uses an oscillating mirror to continuously scan perpendicular to the direction of flight (Figure A-2). Six lines are scanned simultaneously in each of the four spectral bands with each mirror sweep. The along-track progression of the scan lines is provided by the forward motion of the spacecraft. Reflected energy is sensed simultaneously by an array of six detectors in each of the four spectral bands. These data are telemetered directly to ground data acquisition stations or recorded on magnetic tape for delayed transmittal to the ground. Finally these data are processed at the NASA Goddard Space Flight Center to produce computer tapes and to convert the digital data to image formats. Each Landsat scene covers an area 115 x 115 statute miles and each picture element (pixel) in the scene represents about 1.1 acres (2,332 square meters).

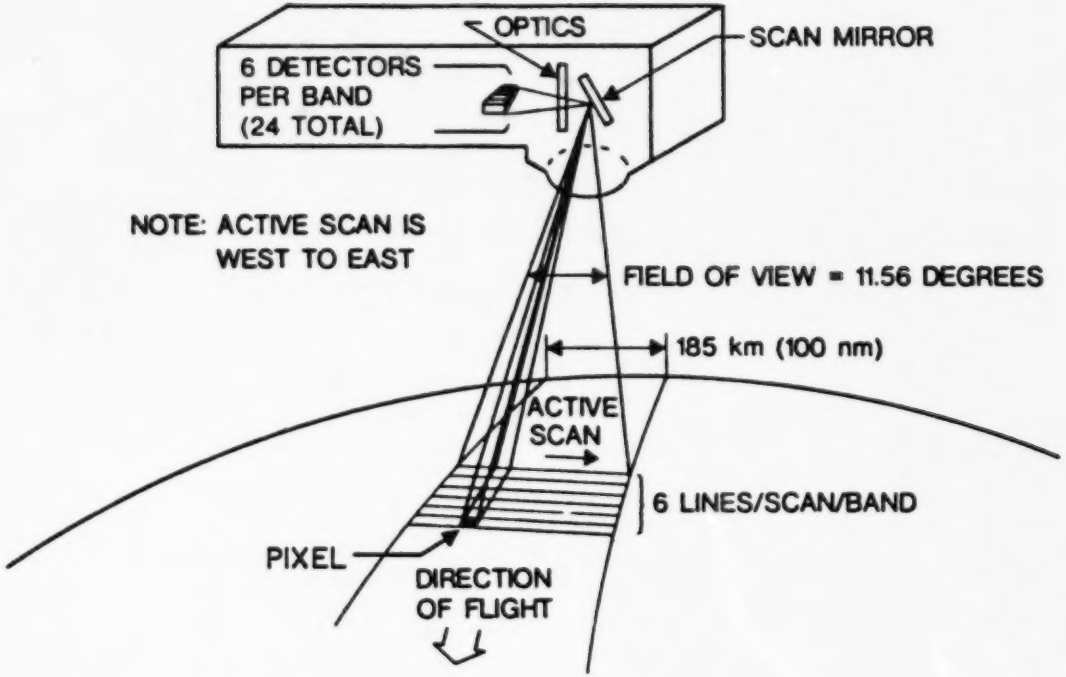

Figure A-2. Landsat Multispectral Scanner Imaging System (Simplified)

APPENDIX B

DATA REDUCTION AND PROCESSING PROCEDURES

The flow of data processing within the Data Analysis System (DAS) is graphically depicted in Figure 3. There are minor differences in processing aircraft-acquired and Landsat digital data.

PREPROCESSING AND DATA TRANSFORMATION

Conventional digital computers such as the one used in the DAS cannot read the data format produced by an aircraft multispectral scanner (MSS), so a special device has been designed to convert aircraft MSS data into the format expected by a conventional computer. Once this conversion (termed decommutation) is made, standard data processing techniques can be applied to all other functions.

The subsequent reformatting process converts the decommutated aircraft data into a format compatible with the software of the DAS. The digital tape that is produced is screened to determine if problems are associated with the data, such as sun angle/scan angle situations, and defective or missing data records. These problems are handled by software in the preprocessing data transformation block.

PATTERN RECOGNITION

Data processing and analysis begin when the software programs contained in the pattern recognition block are implemented. It is within this block that the data are classified. The four basic steps in pattern recognition are implemented in accordance with the following guidelines.

Training Sample Selection

The first, and probably the most important step following data acquisition is the selection of training samples from which statistics are computed and a signature developed for a given class.

Selection of Training Samples

Aircraft-acquired color, color infrared, or black-and-white photography are used in the preselection of training fields. Customarily, both the photography and scanner data are collected simultaneously, but it is the

photography that provides the analyst with first-look capability and the capacity to use photo-interpretation techniques to locate and delineate features of interest. To optimize data acquisition and at the same time make it easier for the analyst to interpret, photography and digital data are obtained simultaneously.

In the selection of training samples, the image analyst attempts to distribute them evenly throughout the geographic area covered by the scanner. A relatively even distribution of samples will in most cases:

1. Account for variations in ground-cover conditions in the area imaged and,

2. Prompt field teams to observe a larger geographic area in which additional fields may be selected as supplements or replacements of invalidated fields. In the process of traveling between preselected training samples, field personnel frequently observe features or conditions which are unique enough to include them as additonal training samples. By covering a wide area in the field, the potential for adding representative samples is immeasurably increased.

Whether identified by photo-interpretation or field observation, every training sample must be precisely located on the photographs. In fact, whenever possible, samples are located so that geographic features can help in locating them on the photography, in the field, and on the screen of the DAS TV display. These training samples may be delineated on translucent overlays and annotated with pre-established coding from the various categories in the land-cover hierarchy being used. Fiducial marks and distinctive geographic features such as roadways, pipelines, and water bodies are traced for assistance in overlay orientation.

In addition to surface conditions such as size, homogeneity, and uniformity, anomalies in scanner data may invalidate one or more training samples. It must be recognized that no single sample can be expected to adequately represent every other area of similar surface material within the scanner field of view. Field verification of any group of preselected samples may result in as much as a 20% attrition rate. All samples identified should be plotted and coded on maps, imagery, and overlays with the same precision and consideration as in the preselection process.

Computer Location of Training Samples

Following the photo-interpretation, the analyst locates these same training samples in the digital data. This task is accomplished through the use of an Interactive Display System (IDS) (Figure 2). This device, intergrated with the computer and described in detail by Whitley (1976), premits a visual display of reformatted digital data on a cathode ray tube. The data can be displayed in either a black-and-white or color mode. In this manner, polygon-shaped training sample boundaries previously located on the photography can be located through the use of a movable cursor. By this method each corner of the sample is located and the corresponding scanline/element coordinates are recorded by the computer. This process is repeated until all

training samples have been located and the analyst is ready to compute statistics on each training sample or group of training samples (classification category).

Statistical Computation

The next step is the computation of statistics associated with the digital data contained in each training sample. This step can occur after each individual training sample is located, or all samples can be chosen, stored, and the statistics computed for each simultaneously, whichever is more convenient. Regardless of the technique followed, the resultant statistics, e.g., mean, mean vector, covariance matrix, and standard deviation, define the distribution of training sample data in a multidimensional space (which in turn is defined by the number of channels being used). These multispectral statistics characterize the sample and are referred to by the term "spectral signature".

First, the statistics are computed for each training sample and the statistical homogeneity of the sample population must be determined. This means that the histogram of the data (for all channels) appears to be normally distributed, with no "outliers" (data points located at some unusually large distance from the mean) or bimodal tendencies (Figure B-1). Second, the actual number of data points (elements) in each sample must be of sufficient number to constitute a statistically "valid" population (generally greater than 30 elements). By selecting the largest possible training sample (and hence including the greatest number of elements), statistical tests conducted at a later time can be made with greater levels of confidence.

Third, the analyst determines whether the coefficient of variation for any and all channels is sufficiently low. Experience with various data sets indicates that acceptable values for the coefficient of variation lie in the vicinity of 10 to 15% for aircraft data. However, this value is by no means considered absolute; the investigator should be prepared to change the values of the coefficient of variation in response to the quality and type of data being processed.

Fourth, the overall quality of the data must be considered. As previously mentioned, outliers or bimodal tendencies (Figure B-1) would indicate potential problems with training sample validity. Other problems include (but are not restricted to) data value skipping observable as skips or gaps in the histogram at regular intervals (Figure B-2), saturation (data values consistently occurring at the extreme high limit of the signal for a particular channel), and pure samples (no variance - all data have the same radiometric value - primarily a problem associated with water). When all values are identical for a given material, the statistical equation used in classification are invalid (matrix cannot be inverted).

If none of these problems mentioned above are observed, the statistics are stored for later use. If, however, problems are encountered, remedial action should be taken, such as dropping the sample or relocating the sample in the digital data and developing a new set of statistics. This latter action is highly desirable in situations where the particular training sample in question is the only one representing a particular land-cover type. If

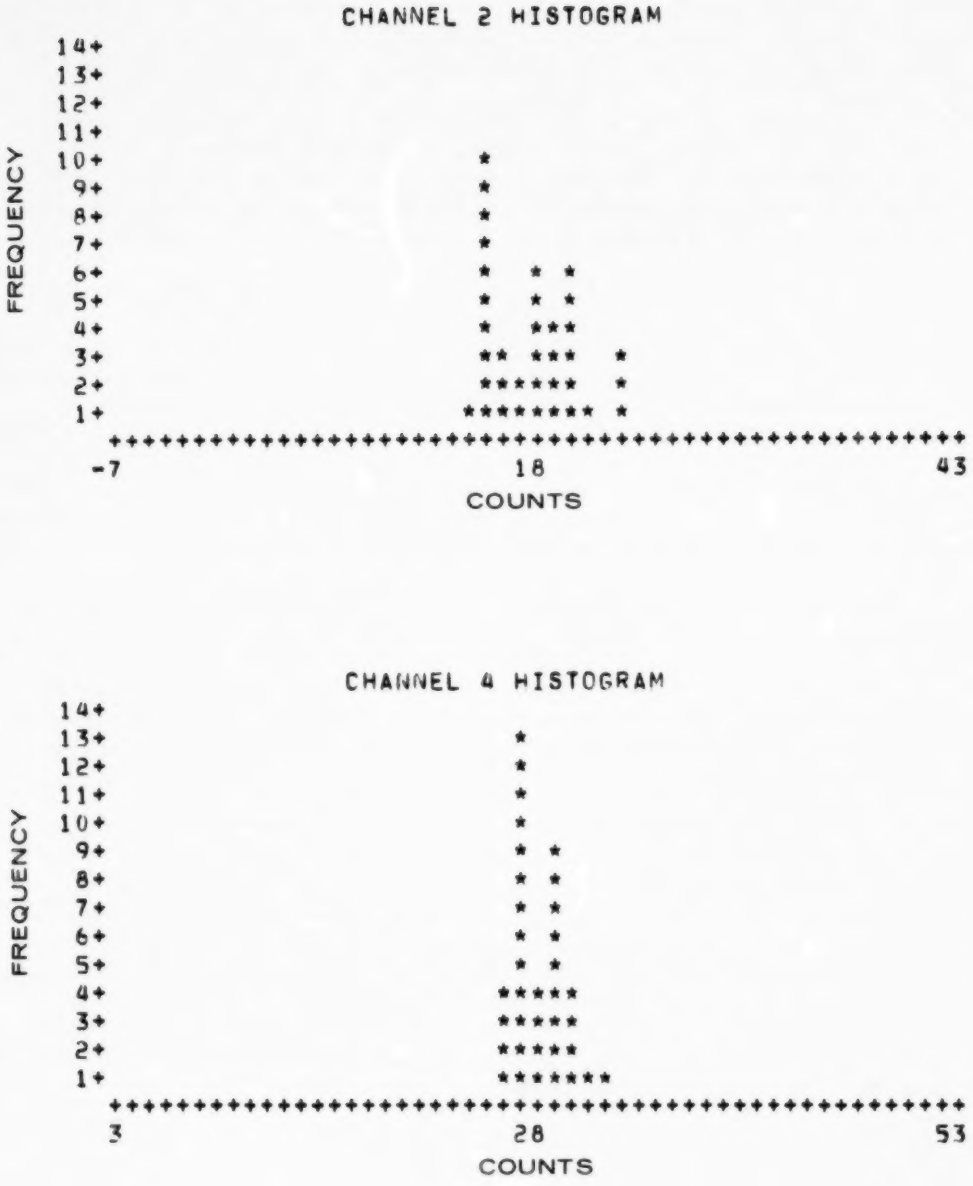

Figure B-1. Histograms of Data Illustrating Outliers (top) and Bimodal Tendencies (bottom) of Scanner Data.

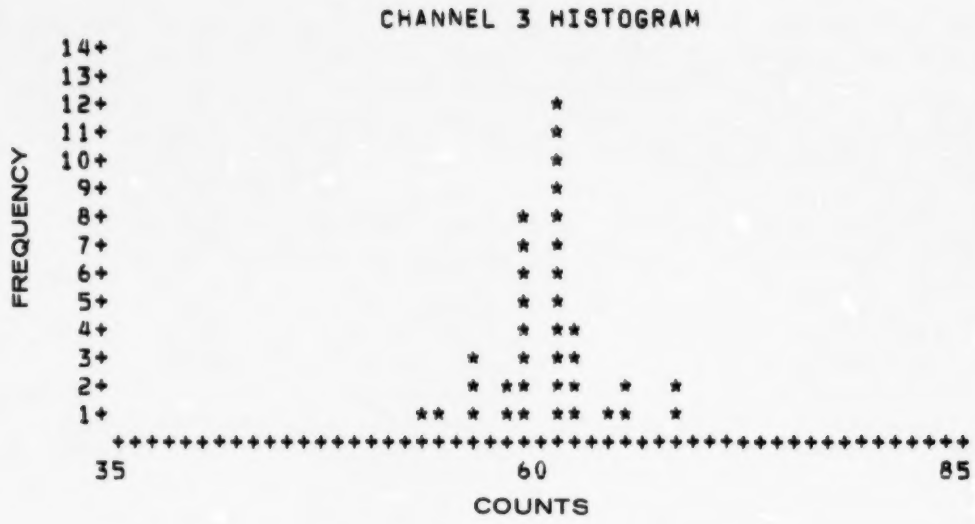

Figure B-2. Histogram of Scanner Data Illustrating Data Value Skipping or Gap Tendencies of the Data.

this type is significant, the loss of the training sample might prove critical to the overall utility of the resultant product. If, however, the sample is but one of several representing a particular land-cover category, the loss will not degrade the end product.

For these reasons it is highly recommended to locate at least three training samples per land-cover category. By doing so, the possibility of "losing" an important land-cover type is minimized. In addition, the need for reselection of a training sample could be avoided.

Training sample selection and subsequent computation of statistics are activities conducted on the IDS (Figure 2). This system is composed of an operator's console, which allows for communication between the computer and the investigator, and an image display device (a color TV display). In addition, either a disk or a solid-state memory that stores the information derived by the computer and places it on the display is included as part of the IDS.

Training sample statistics that are to be used in subsequent processing steps are stored on a separate computer disc memory file. However, before proceeding to the classification of all elements in the data set, one more statistical analysis is necessary. This additional step, referred to as divergence analysis, permits the investigator to determine to what extent any particular class is spectrally separable from any other class. Those not separable can be meaningfully grouped due to their spectral similarity.

Channel Selection

The Environmental Monitoring and Support Laboratory-Las Vegas (EMSL-LV) airborne scanner contains 11 channels. However, software developed for the DAS restricts the number of input channels to the classifier to a maximum of four. This is not a severe limitation, as four channels give almost the same accuracy as a greater number, and computation speed is greatly improved by limiting the number of channels.

For EMSL-LV purposes, the most desirable technique for reducing the number of channels to four, utilizes the program SEPARATION. SEPARATION has been designed to select from an input set of "n" channels, the four channels that will provide the spectral separation of the training samples used as inputs. Only one set of four channels will be selected for use in classification. The statistics generated for the individual training samples are utilized in a manner similar to that described by Jones (1976). The statistics are then recomputed for the four chosen channels for each training sample. Divergence analysis is conducted and groupings based on only four channels are made.

Classification of Digital Data

Two software programs are required for classifying the data. The first program (ELIPSE) computes, from the class statistics, the hyperellipsoidal decision boundaries used for classifying the digital data. Each hyperellipsoidal table partitions off a subspace of the n-dimensional space (where n = number of channels) in which classification of the digital data is to occur. The program also prints out other parameters necessary to implement the second of the two software programs.

Tables constructed by ELIPSE, plus the computer compatible tapes from which the training samples were selected, are used as inputs to ASSIGN, the second software program. Each element is located in n-dimensional space and checked to see if it falls within the hyperellipsoidal subspace of any class. If so, it is assigned (hence "ASSIGN") to the land-cover category represented by that particular class. If the element does not fall within any class subspace, it is assigned to the "uncategorized" group which is a group of land-cover types for which no training sample sites were chosen. The next element in the scan line is then considered. This process is continued until all data have been classified.

The output from ASSIGN is the classified data on magnetic tape, and line printer output with statistics indicating the number of elements (and percent of all elements) in each class (Table B-1). The tape serves two purposes. First, it can be used to furnish acreage statistics, calculated by an acreage software program. Second, the classified data tape is used in viewing the classified scene on the IPS display or in the production of hard copy products, e.g., color or black-and-white film recordings (to desired scale), or electrostatic printer/plotter paper products. The IPS viewing is generally done first to evaluate the classification results. Colors, at the discretion of the investigator, can be assigned to each class. Colors are generally assigned in such a manner that various intensities of one color are used for classes representing varying conditions of a particular land-cover category.

TABLE B-1. SUMMARIZATION OF CLASSIFICATION RESULTS BY CLASS (EXAMPLE)

Class	Pixel Count	Percent of Scene	Acres	Square Miles
0	6,037	3.28	3,409	5.33
1	1,830	.99	1,033	1.61
2	37,046	20.12	20,918	32.68
3	19,946	10.83	11,262	17.60
4	53,302	28.94	30,096	47.03
5	52,673	28.60	29,741	46.47
6	3,533	1.92	1,995	3.12
7	1,101	.60	622	.97
8	3,838	2.08	2,167	3.39
9	1,223	.66	691	1.08
10	3,640	1.98	2,055	3.21
TOTAL	184,169	100.0	103,989	162.50

APPENDIX C

SCIENTIFIC NAMES OF VEGETATIVE TYPES IDENTIFIED IN PHASE I OPERATIONS

Common Name	Genus and Species
Alkali sacatone	Sporobolus airvoides
Blue grama	Bouteloua gracilis
Greasewood	Sarcobatus vermiculatus
Green needlegrass	Stipa viridula
Juniper	Juniperus sp.
Mormon tea	Ephedra sp.
Needle-and-threadgrasses	Stipa comata
Pinyon pine	Pinus edulis
Rabbit brush	Shrysothamnus sp.
Sagebrush	Artemisia sp.
Snakeweed	Gutierrezia sp.
Wheatgrass	Agropyron sp.
Winterfat	Eurotia lanata